KFKI
1/1969

NEW EXPERIMENTS ON GIANT ZERO BIAS TUNNELING ANOMALY: EFFECT OF IMPURITY DISTRIBUTION

F. Mezei

Institute for Experimental Physics, Eötvös University, Budapest

HUNGARIAN ACADEMY OF SCIENCES
CENTRAL RESEARCH INSTITUTE FOR PHYSICS

BUDAPEST

NEW EXPERIMENTS ON GIANT ZERO BIAS TUNNELING ANOMALY: EFFECT OF IMPURITY DISTRIBUTION+

F.Mezei

Central Research Institute for Physics, Budapest

and

Institute for Experimental Physics, Eötvös University, Budapest

Zero bias tunneling anomalies are believed to be due to some kind of interaction between conductance electrons and impurities at the barrier. The question arises naturally whether only impurities in the immediate vicinity of the junction surface are effective or those placed inside the electrode metal as well. The effects of the latter type impurities can be reasonable regarded as local disturbances in the conductance electron wave functions rather than modification of the tunneling matrix elements like impurity assisted channels. This would give an opportunity to investigate bulk impurity effects via tunneling. In the present work new type of experiments were started to investigate this problem.

The dynamical resistance of $Al-Al_2O_3-Al$ tunnel junctions $R(V)=dV/dI$ versus the voltage V was measured by standard modulation technique. The junctions were fabricated in the following way. An aluminium strip evaporated at first was oxidized at atmospheric pressure in air. The second aluminium elektrode was prepared in two steps. First a thin Al layer of thickness $D = 20 - 200$ Å /hereafter referred to as " additional layer"/ was deposited onto the oxide surface as shown in Fig. 1. /The thickness D was measured by optical absorption./ Before evapeirating the rest of the second Al electrode this half-made junction stayed a "waiting time" t of the order 10 minutes at a pressure 2.10^{-5} torr in the evaporation chamber. In this way we have got junctions exhibiting giant zero bias resistance maximum, which is most probable the same effect that was recently found in several junctions prepared by different techniques [1,2,3.] Thus with small D the junctions show the same quasi-logarithmic anomaly in $R(V)-R_o(V)= \Delta R(V)$ curve /$R_o(V)$ is the background resistance, Fig.2./ as found by Shen and Rowell[4], and exactly the same temperature dependence as in earlier experiments. The similarity is pronounced by the fact, that in some cases we have found even the well known [3,4,5,6] conductance peak at zero bias superposed on the broad resistivity maximum, however at the present we can not reproduce this effect at will.

We have investigated the dependence of the anomaly on the waiting time t and on the thickness of the additional Al layer D, shown in Fig.3. and 4. respectively. We mention that the change of the evaporation rate of the additional layer between 5-50 Å/sec has no serious effect, so we might think that this layer is rather uniform. The junctions have shown good gap characteristics under the critical temperature close to the bulk value for Al 1.20 K^o. Thus no indication of granular [7] or sandwich [8] structure occured concerning the value of T_c.

We believe that the anomaly found is due to some kind of impurities formed during the waiting time on the surface of the additional layer, which in turn got inside the second Al electrode by the completition of the junction. This is established by the followings:

The anomaly was found to be due to the interaction of the additional layer and the low pressure atmosphere within the evaporation chamber. When the pressure was increased during the waiting time to 10^{-3} torr, the anomaly occured after much shorter time t, i.e. after a few seconds. On the other hand without the additional layer no anomaly was found at all. At the present circumstances /room temperature, 2.10^{-5} torr/ this interaction can not be expected to display any dramatic effect on the stucture of the additional layer such as formation of a second insulating oxide layer as in the experiment of Giaever et al. [9] Control measurements have shown no insulation beyond the experimental resolution 10^{-4} Ω/mm^2, and no decrease in the optical absorption of the additional layer occured beyond the error 0.5% indicating an oxidation rate less then one atomic layer.

Another important feature is that increasing the thickness of the additional layer there is a pronounced change in the shape of the anomaly plotted as G (V) = dV/dI vs, V, Fig.5. In the conductance the contributions of different macroscopic regions of the junction are simply summed up. This fact rules out the assumption that the very thin portions of the highly non-uniform additional layer were effective only in causing the anomaly, and the decrease of its amplitude with increasing D were due to the decrease in area of such thin macroscopic regions of the additional layer.

Thus we conclude that we have an effect due to some kind of impurities displaced definitely inside the second electrode at about a distance D from the oxide surface. In the formation of these impurities an oxidation process may have an important role. It is probable that considerable amount of tungsten coming from the source filament is contained in our evaporated Al films. The oxidation of W atoms on the surface of the additional layer could give the effective impurities. This idea is supported by the experiments of Klein and Leder [10]. They have found large zero bias anomalies when their Al electrodes were evaporated from W filament at O_2 atmosphere of 5.10^{-5} torr, which did not occur for similar junctions evaporated using Alumina boat and presumably having the same amount of oxigen contained in their Al electrodes [7].

The present experimental results can be explained supposing local scattering of conduction electrons on the impurities as in the theory of Sólyom and Zawadowski considering Kondo scattering [11]. / W-oxides are in fact magnetic/. According to this approach the imaginary part of the scattering amplitude leads to a decrease in the local value of the effective tunneling density of states in the vicinity of the impurity layer. The spatial spread out of this suppression of the density of states is characterized by the coherence length $\xi_c \sim \frac{\pi}{\Delta k_c}$ where Δk_c is the cut-off momentum of the scattering [11]. This is related to the energy of the localized magnetic d level measured from the Fermi energy, and may be estimated to a few percent of k_F [12]. By this ξ_c has to be of the order 100 Å as a typical value being in reasonable agreement with the observed dependence of the conductance anomaly on D shown in Fig.6.

The change, mentioned already, in shape of the G(V) curves shown in Fig. 5. can be explained by supposing that the local disturbances of the conduction electron Green's function die off with increasing distance the more rapidly the farer the energy concerned lies from the Fermi level. The narrowing of the anomaly with increasing t [13]. i.e. impurity concentration, shown up in Fig.3. is explained by taking into acxount in a selfconsistent manner the suppression of the density of states in the Kondo scattering itself [12]. This effect was observed in other experiments on giant zero bias anomalies as well [3,5]. We mention that the temperature dependence of these anomalies is found to be more rapid than predicted only by the standard kT smearing. We believe this to be due to the selfconsistancy as well, by that the Kondo scattering amplitude is expected to depend on the thermally averaged actual density of states near the impurity layer rather than on the unperturbed one. From theoretical point of view a more detailed discussion of these effects will be presented elsewhere.

It is worth mentioning that in the present experiment the inplantation of impurities causes presumably negligible additional changes in the structure of the junctions. Just because of this there is a possibility to compare qualitatively the absolute value of the resistance of the "normal" and "anomalous" junctions. In spite of the fact that the value of the zero bias resistance is not a well reproducible parameter of tunnel junctions, a general tendency could be observed that anomalous junctions give considerable higher R(0) values than the normal ones made on the same substrate. If so, this rules out the assisted tunneling mechanism [14] for the present case, while it is in agreement with the Sólyom-Zawadowski theory.

In sum in the present work giant zero bias anomaly was found occuring under entirely new preparation conditions. The junctions used in previous experiments were prepared by rather brutal methods like evaporation of impurities, oxidation at atmospheric pressures, which can cause uncontrolable additional changes in the junction structure. Beside the coherence length effects, we see the major importance of the present experiment in finding such an anomaly clearly due to extremly slight modification in the preparation. This suggests that giant zero bias anomalies are caused by a dramatic effect of a few atoms or molecules. If this is not the Kondo scattering which seems to be the only known effect strong enough, it may not be much less interesting. In agreement with our conclusion recent measurements by Wyatt and Lythall [15] have quantitatively established that the evaporation of impurities in a total quantity amounting only to a fraction of a uniform monatomic layer may cause large anomalies as well.

The author is indebted to Professor L. Pál and Prof. E. Nagy for their continous interest in this work, and to Dr.A.F.G. Wyatt for making him possible to perform some control measurments and making new experimental data available prior to pulication. He wishes also to thank many stimulating discussions to Drs. A. Zawadowski, A.F.G. Wyatt, C. Hargitai , J.Sólyom and D. Lythall.

References

+ Part of this paper was presented on the Eleventh International Conference on Low Temperature Physics, St.Andrews, 1968.

[1] J.M.Rowell and L.Y.L. Shen, Phys. Rev. Letters, 17, 15/1968/.

[2] A.F.G. Wyatt and D.J. Lythall, Phys.Letters, 25A, 541/1967/.

[3] F.Mezei, Phys.Letters, 25A, 534/1968/.

[4] L.Y.L.Shen and J.M.Rowell, Phys.Rev. 165,566/1968/.

[5] L.Y.L.Shen , Phys.Rev. Letters, 21, 361/1968/.

[6] D.J. Lythall and A.F.G. Wyatt, Phys.Rev.Letters, 20,1361/1968/.

[7] R.W. Cohen and B. Abeles, Phys.Rev. 168. 444/1968

[8] M.Strongin, O.F. Kammerer, D.H.Douglass, Jr., and M.H.Cohen, Phys.Rev.Letters, 19,121/1967/.

[9] I.Giaever and H.R. Zeller, Phys.Rev.Letters, 20, 1504/1968/.

[10] J.Klein and A.Leger, Phys.Letters, 28A, 134/1968/.

[11] J.Sólyom and A. Zawadowski, Phys. of Cond.Matter, 7,325 and 342/1968/.

[12] J.Sólyom and A. Zawadowski, Lecture on the Eleventh International Conference on Low Temperature Physics, St.Andrews, 1968.

[13] This rules out once more the capacitance mechanism [9] in the present case, since a growing of oxide layer reduces the capacity of grains, which would lead to a broadening of the anomaly.

[14] C.B. Duke, S.D. Silverstein and A.J. Bennett, Phys.Rev. Letters, 19,315/1967/.

[15] A.F.G. Wyatt and D.J. Lythall, private communication.

Figure Captions

Fig.1. The schematic structure of the junctions.

Fig.2. The plot of the normalized anomalous resistance $\Delta R(V)/\Delta R(0)$ for a few junctions versus the logarithm of the voltage V./T = 1,7 K^o/.

Fig.3. Normalized resistance R(V)/ R(0) vs. the voltage V characteristics' for t = 27,9,3 and 1 minutes, curves a,b,c and d respectively; D = 60 Å, T = 2K^o. /The curves b, c, d are shifted upwards./

Fig.4. Normalized resistance R(V)/ R(0)vs. the voltage V characteristics' for D = 25,60,100 and 150 Å, curves a,b,c and d, respectively; t = 5 min, T = 2 K^o. /The curves b,c,d are shifted upwards/.

Fig.5. The characteristics' shown in Fig.4. plotted as normalized conductance G(V) / G(-200 mV) vs. the voltage V. /The curves b,c,d are shifted upwards/.

Fig.6. The conductance anomaly $\Delta G(0)/ G_o(0)$ /where $\Delta G(V) = G(V) - G_o(V)$ and $G_o(V)$ is the background conductance/ as a function of D, for t = 5 min., T = 1,7 K^o.

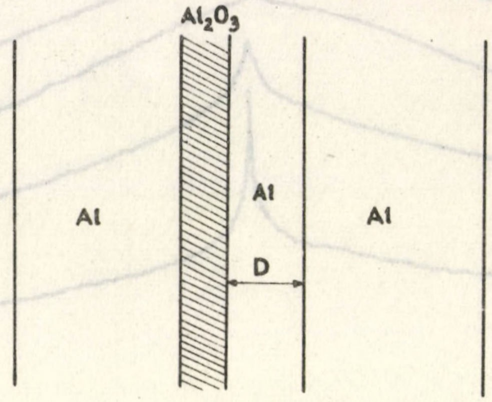
Al_2O_3
Al
Al
Al
D

Fig. 1.

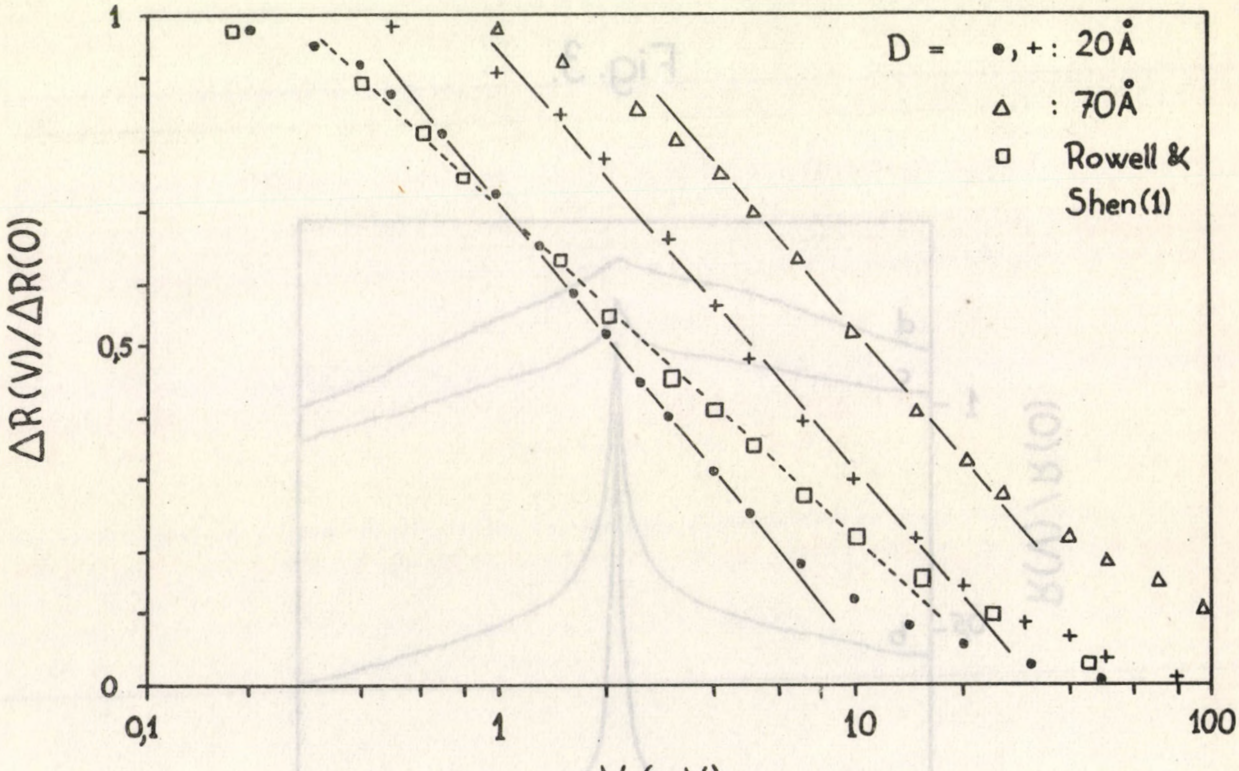
D = •, + : 20Å
△ : 70Å
□ Rowell & Shen(1)
ΔR(V)/ΔR(O)
1
0,5
0
0,1
1
10
100
V (mV)

Fig. 2.

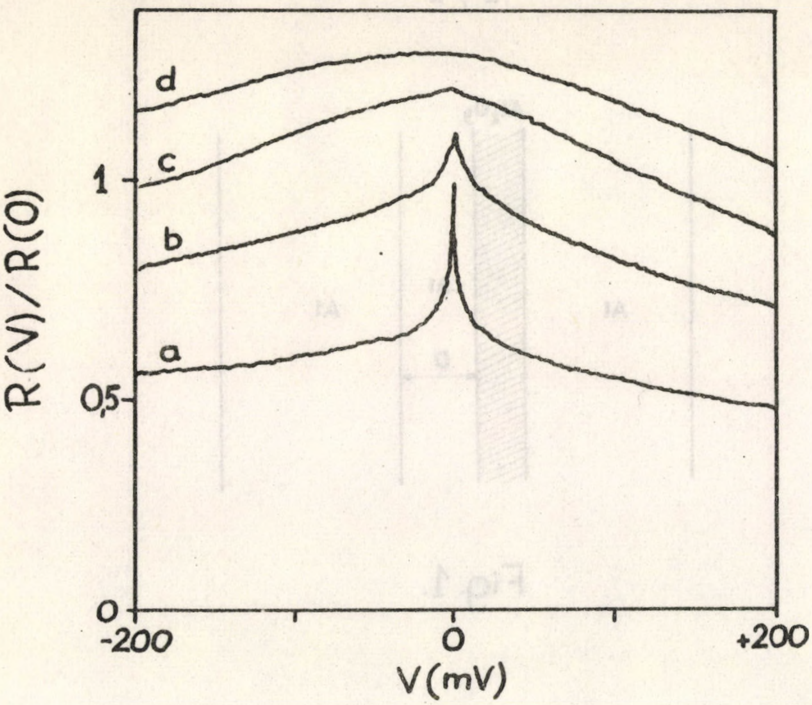

Fig. 3.

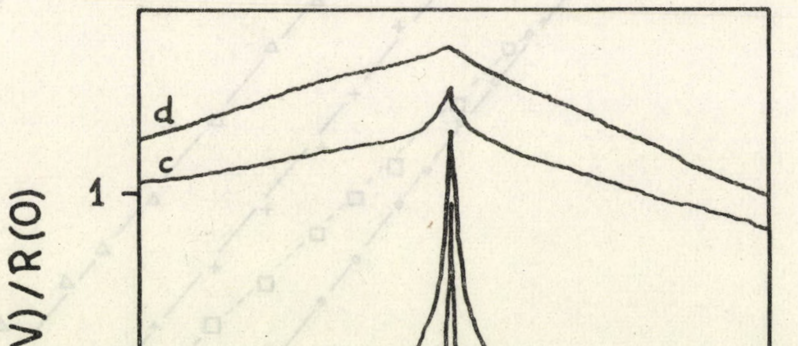

Fig. 4.

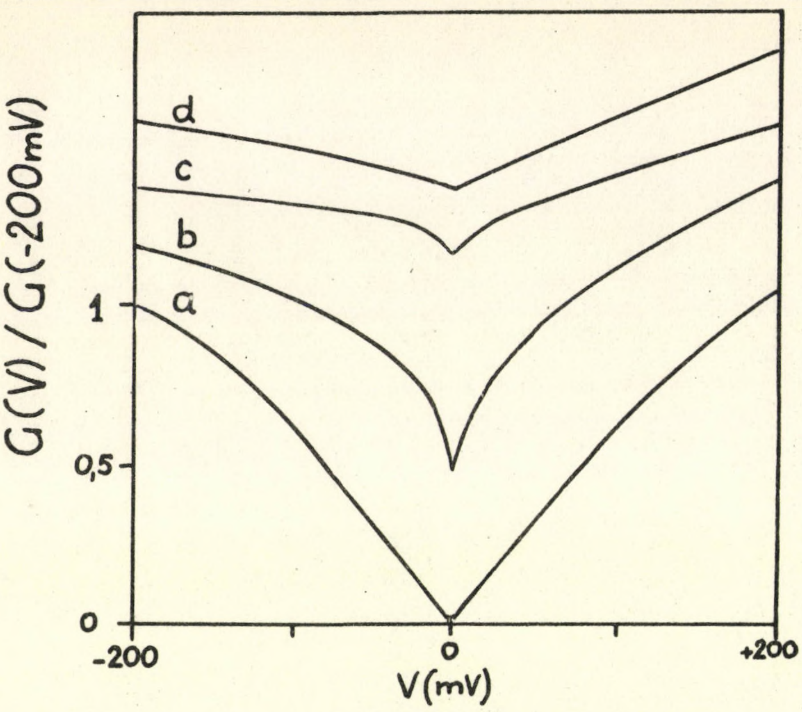

Fig. 5.

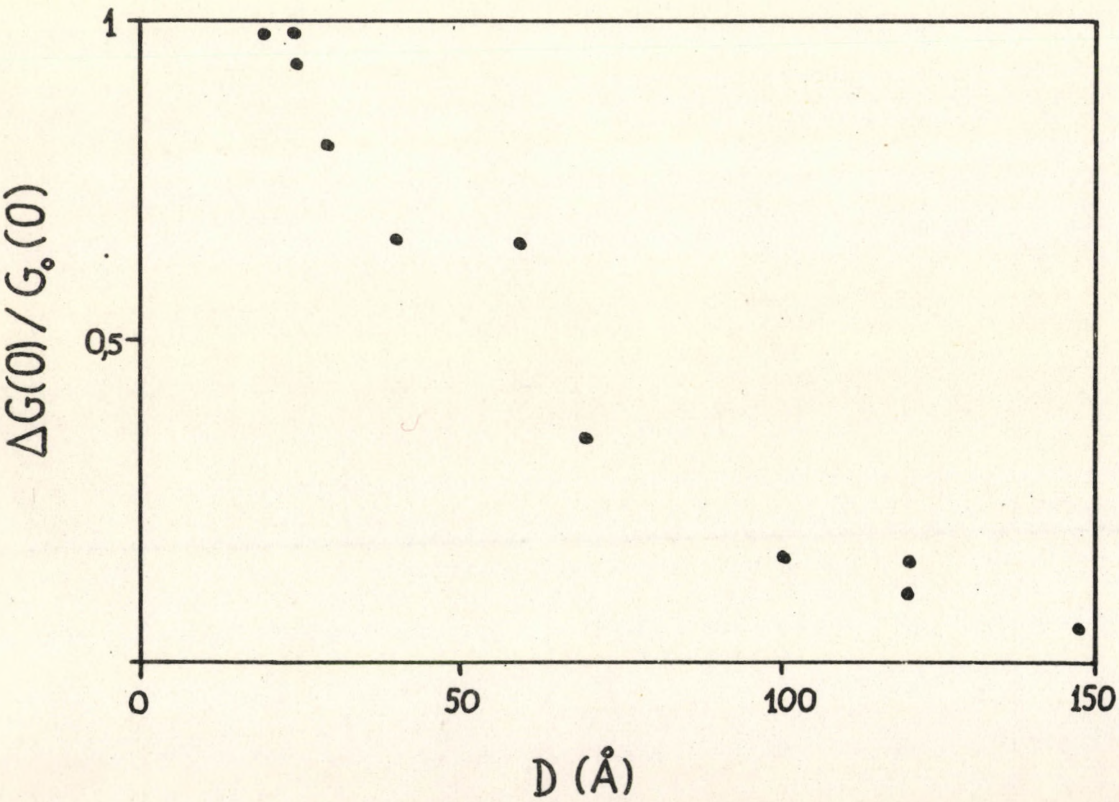

Fig. 6.

Printed in the Central Research Institute for Physics, Budapest
Kiadja a Könyvtár- és Kiadói Osztály. O.v.: dr.Farkas Istvánné
Szakmai lektor: Zawadowski Alfréd. Nyelvi lektor: Hargitai Csaba
Példányszám: 100 Munkaszám: 4168 Budapest, 1969.január 7-én
Készült a KFKI házi sokszorositójában. F.v.: Gyenes Imre